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ABSTRACT

The solid state spectrometer on the Einstein Observatory and the GSFC cosmic X-ray spectrometer on OSO-8 have observed the X-ray spectrum of SN1006. The data can be well-represented by a power-law model with $\alpha = 1.2$, similar to the spectrum of the Crab nebula. This is in contrast to the radio and X-ray maps of SN1006 which show a shell structure more typical of SNR with thermal X-ray emission. The X-ray spectrum is suggestive of non-thermal synchrotron emission, raising the possibility that the remnant of SN1006 contains a source of relativistic electrons.

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I. INTRODUCTION

Radio astronomers have traditionally divided supernova remnants (SNR) into two catagories, shell source and Crab-like sources. The shell sources are typified by Tycho's SNR and the Cygnus Loop, objects with steep spectral indices ($\alpha \gtrsim .5$) and shell-like spatial distributions. The prototype Crab-like (i.e. pulsar-driven) source is the Crab nebula with identifying radio characteristics of a filled-center spatial distribution and a flat spectrum ($\alpha \lesssim .2$). In both cases, the radio emission is synchrotron in natur but for the shell sources the magnetic field and the relativistic electrons are most likely swept-up from the ISM (van der Laan 1962a,b) while the relativistic electrons in Crab-like sources derive from a central pulsar, as suggested by the spatial distribution of the radio emission. X-ray spectra of shell sources have been observed to be thermal in origin as evidenced by profuse line emission (Becker et al. 1979,1980a,b) while the Crab nebula X-ray spectrum is a featureless power-law with $\alpha = 1.15$.

The solid state spectrometer (SSS) on the Einstein Observatory engaged in a program of surveying the X-ray spectra of SNR, from which results for Cas A, Tycho, and Kepler (Becker et al. 1979, 1980a,b) have already been reported. These three remnants can all be catagorized as shell sources based on their radio properties and all three have X-ray spectra dominated by line emission. The remnant of SN1006 is approximately twice as old as the above sources, and on the basis of radio observations should also be considered a shell source (Stephenson et al.

1977). This paper presents the X-ray spectrum of SN1006, which leads to a reconsideration of the traditional distinctions between shell and Crab-like SNR.

II. OBSERVATIONS

The SSS experiment has been described in detail by Joyce et al. (1978) and the data analysis procedures are detailed by Holt et al. (1979). It is important to note that the SSS field of view has a 6 arc min diameter, considerably smaller then SN1006. To carry out these observations, the SSS was pointed at 4 different fields centered at RA(1950) and δ (1950) of ($224^{\circ}71$, $-41^{\circ}92$), ($225^{\circ}17$, $-41^{\circ}58$), ($225^{\circ}00$, $-41^{\circ}75$), and ($225^{\circ}19$, $-41^{\circ}67$), thus sampling both the rim (3 of the 4 positions) and the center of the source. However, the data from the central region is of relatively poor quality and will not be discussed.

The composite spectrum for the rim of SN1006 is shown in Figure 1. (This represents only a fraction of the total emission due to the small field of view). The data can be well-represented by either a power-law with a spectral index of 1.2 ± 0.2 with a equivalent hydrogen column density N_H of $9 \pm 3 \times 10^{20}$ cm^{-2} or a featureless thermal bremsstrahlung model with $kT = 2.7 \pm 0.3$ keV and $N_H = 6 \pm 2 \times 10^{20}$ cm^{-2} (errors are 90% confidence limits). Both models are improved by the inclusion of an emission feature at 1.85 keV with an equivalent width of 50 eV, but the line is significant at only the 2σ level.

The remnant of SN1006 was also observed by the GSFC Cosmic X-ray Spectrometer (CXS) xenon detector (see Pravdo et al. 1976 for description) on OSO-8 for six days. The data were consistent

with either simple thermal bremsstrahlung emission of kT = 6 ± 2 keV or a power law with spectral index α = 1.2 ± .5. In either case, there was no evidence for Fe line emission at 6.7 keV and we can place a 90% confidence upper limit to the equivalent width of 600 eV for such a feature. (This can be compared to the Cas A X-ray spectrum which shows an Fe line with an equivalent width of ~ 1270 eV (Pravdo et al. 1976)). It would appear, therefore, that the same power law can be reconciled with both the SSS and CXS data, while a single bremsstrahlung cannot.

III. DISCUSSION

The spectra of SN1006 measured by the SSS and the CXS are in excellent agreement with previous observations (see Toor 1980 and references therein). Although Toor (1980) noted the consistency of the spectrum with a power-law like that of the Crab nebula, his results could not rule out a two-component thermal model or the presence of emission lines. The present data place limits on the line emission of Si XIII and Fe XXIV which are substantially below the line strengths observed in young shell remnants. Although the spectrum of SN1006 may be consistent with a single high temperature thermal component (although the SSS and the CXS disagree in detail) it lacks a low-temperature (~ 500 eV) thermal component typically found in other remnants. The presence of a 500 eV component would be clearly discernible with the high spectral resolution of the SSS. For all practical purposes, the X-ray spectra of SN1006 and the Crab nebula are indistinguishable above 0.5 keV, differing only by the amount of absorption due to interstellar material.

Itoh (1979) has questioned the reality of equilibrium low temperature X-ray components in SNR. He points out that if the hot plasma is not in collisional equilibrium, emission lines typical of a 0.5 keV plasma could be present even in the absence of such a plasma. Therefore, it follows that the absence of such lines in SN1006 may be indicative of the extent of departure from equilibrium rather then the absence or presence of a true low temperature component.

It is important to note that the imaging proportional counter (IPC) on the Einstein Observatory has detected, in addition to a hard ($E > 0.5$ keV) component distributed in a partial shell, a very soft ($E < .5$ keV) component distributed fairly uniformly across the remnant (Pye et al. 1980). This soft component cannot be an artifact of non-equilibrium conditions because it does not originate in the same volume of space as the harder emission. If this soft component is an analog to the soft components found in other SNR, its unusually low temperature could explain the absence of strong lines below 4 keV. Even so, some line emission should be associated with the high temperature component, particularly a 6.7 keV line from ionized Fe. The observations presented here show that if such a line is present, it is significantly weaker than those found in other young remnants.

The observations of SN1006 by the SSS differ from those of other young remnants because the SN1006 observations isolated the bright rim from the interior while the other remnants were comparable in size to the field of view. This raises the

possibility that the bright rim of such remnants might also be lacking in line emission. This seems very unlikely in so far as such a large percentage of the total flux of Cas A, Tycho, and Kepler are in line emission that some of line flux must originate in the bright rims.

The arguments against a Crab-like description of SN1006 are strong. Firstly, the radio and hard X-ray emission are distributed in a shell. Secondly, the radio spectrum is steep, typical of shell remnants. Thirdly, there is no direct evidence for the presence of a central pulsar (Fesen, Kirshner, and Winkler 1980; Helfand 1980). And, lastly, the optical filaments observed in SN1006 are similar to those seen in Tycho's SNR (Schweizer and Lasker 1978) suggesting the presence of an expanding shock. If the SN1006 X-ray emission is attributed to thermal processes, either the composition or the state of the responsible plasma must be quite different from that of comparable objects.

On the other hand, the X-ray spectrum of SN1006 appears quite similar to that of the Crab. In particular, the absence of significant line emission above 0.5 keV is in sharp contrast to the X-ray spectrum of any other young shell remnant. We raise the possibility that the X-ray emission is a continuation of the radio synchrotron spectrum. If so, than the relativistic electrons emitting the radiation must originate in the remnant, and not from the ISM. The close agreement between the radio and X-ray spatial distribution (Pye et al. 1980) is consistent with such an interpretation. The two spectra (radio and X-ray) are

consistent if there is a break corresponding to an increase in α of 0.5 at 4 x 10^{13} Hz. If the relativistic electrons have been ejected continuously since an earlier time (~ 500 yrs), the break energy would imply a magnetic field of ~ 10^{-4} G, fairly typical for a SNR.

In summary, the X-ray spectrum of SN1006 between 0.5 and 4.5 keV is consistent with that of the Crab nebula. However, in most other aspects, SN1006 appears to be a shell remnant. In order to determine if the hard X-ray spectrum of SN1006 is thermal or synchrotron in nature, a more sensitive search for X-ray Fe line emission at 6.7 keV should be made. A search for polarized X-ray emission would also differentiate between these two possible mechanisms. If the X-ray emission from SN1006 is found to be non-thermal, it would provide strong circumstantial evidence for the existence of a continuing source of relativistic electrons such as a central neutron star. In addition, the classical distinctions between Crab-like and shell SNR would have to be reevaluated.

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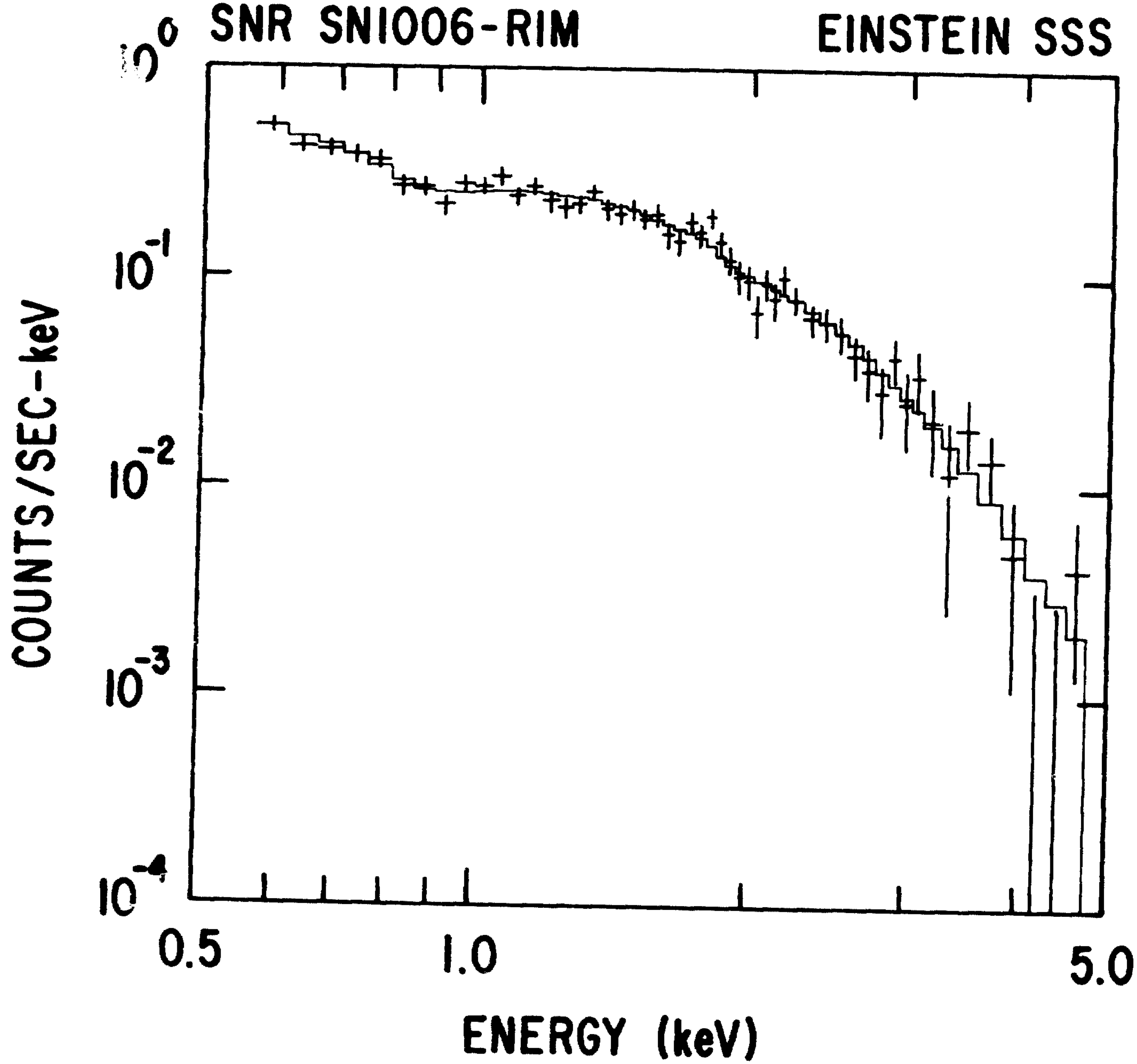
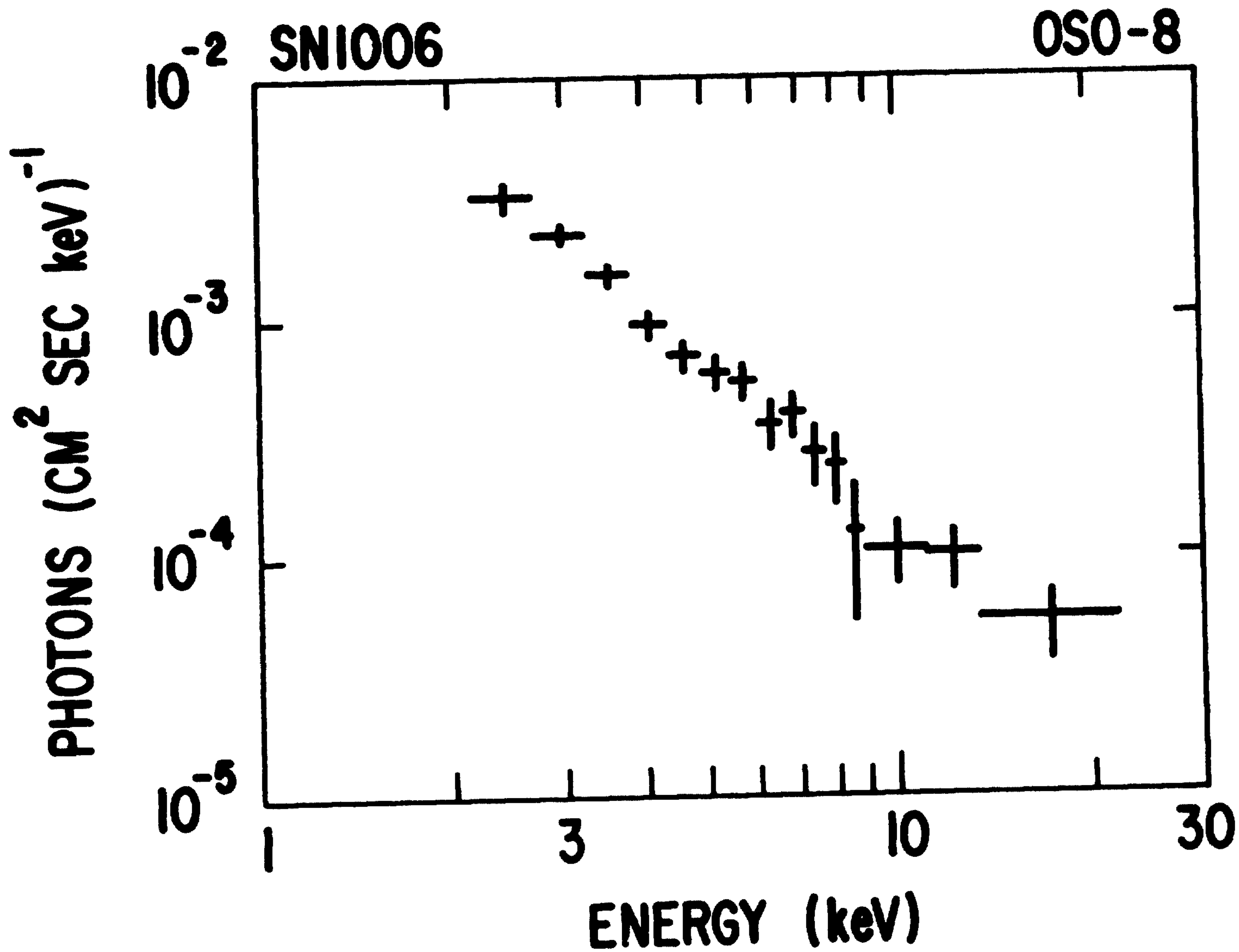
FIGURE CAPTIONS

Figure 1 - The X-ray spectrum of the bright rim of SN1006 as observed by the SSS onboard the Einstein Observatory. Superimposed upon the data is the best fit power-law model (α = +1.2).

Figure 2 - The X-ray spectrum of SN1006 as observed by the CXS onboard the OSO-8 satellite.


SNR SN1006-RIM
EINSTEIN SSS
10^0
10^{-1}
10^{-2}
10^{-3}
10^{-4}
COUNTS/SEC-keV
0.5
1.0
5.0
ENERGY (keV)


SN1006
OSO-8
10^{-2}
10^{-3}
10^{-4}
10^{-5}
PHOTONS $(CM^2 \text{ SEC keV})^{-1}$
1
3
10
30
ENERGY (keV)